Uncertainties in Solar Synoptic Maps and Implications for Space Weather Prediction

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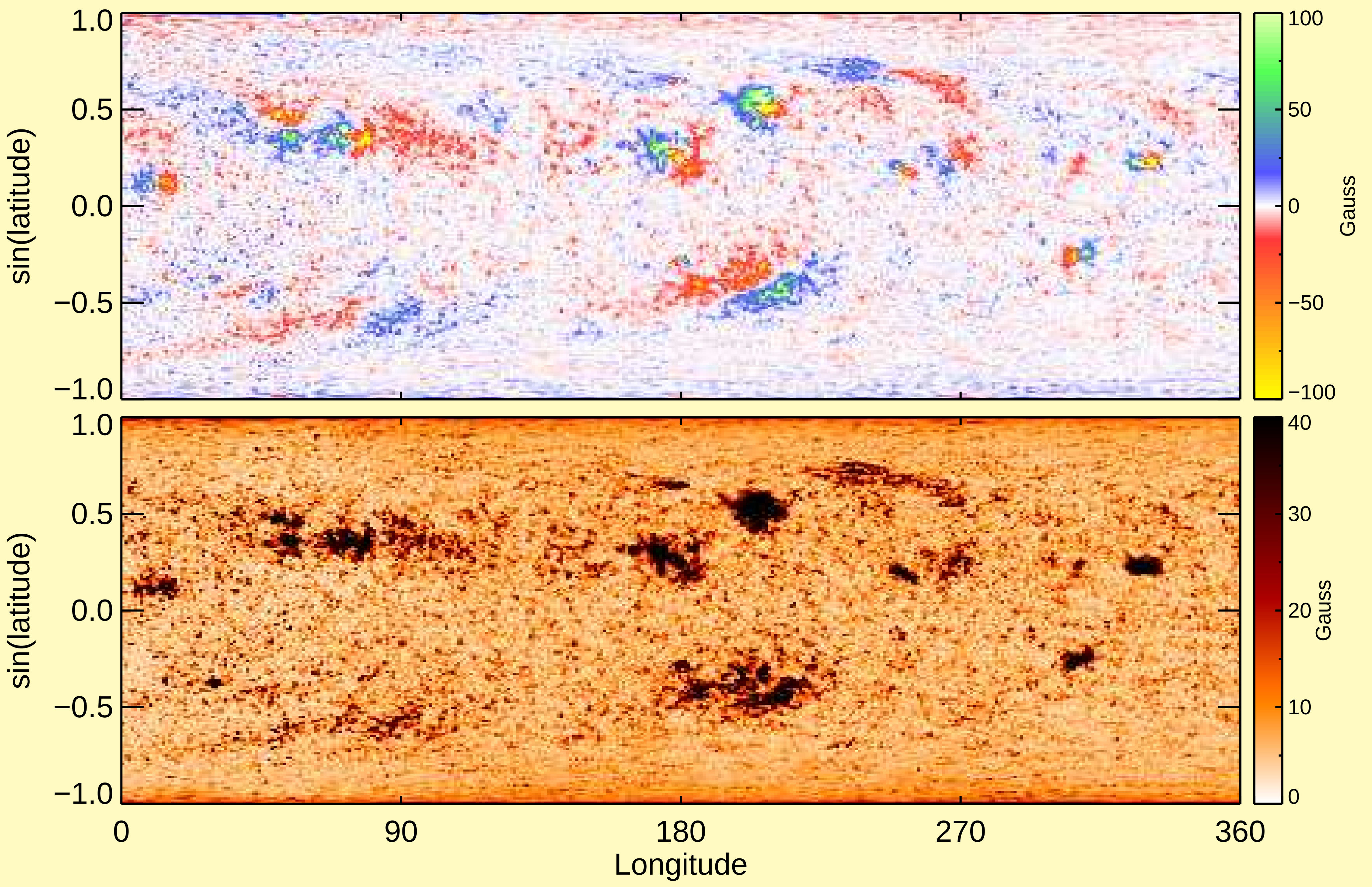
Introduction

Synoptic maps of the photospheric magnetic field are currently used as the primary drivers for all coronal and solar wind models. Until now, however, these magnetic synoptic maps were produced without corresponding uncertainties and were essentially treated by modelers as noise-free input. Uncertainties in synoptic magnetic maps arise primarily from the spatial distribution of magnetic features on the solar disk, their temporal evolution, and noise in the measurements. We recently made a first attempt to estimate some of these uncertainties (spatial variance maps) and evaluated their impact on coronal and heliospheric models (Bertello et al. 2014). These maps are now publicly available from http://solis.nso.edu/0/solis_data.html. Uncertainty maps will likely improve the diagnostic value of existing coronal and heliospheric models by providing quantitative estimates of observational uncertainties. Thus they will open opportunities to refine modelers' scientific conclusions and space-weather forecasts.

As a proof of concept, we show here results for Carrington rotation (CR) 2104 (Nov. - Dec 2010), which corresponds to a period of low solar magnetic activity. From the original Carrington synoptic magnetic flux map we generated a set of 100 simulated maps, using the uncertainty map. In the simulated synoptic maps of this ensemble, the value of each bin is randomly computed from a normal distribution with a mean equal to the magnetic flux value of the original bin and a standard deviation of σ, with σ being the value of the corresponding bin in the uncertainty map. We then computed both a PFSS model (e.g. Altschuler & Newkirk 1969) of the coronal field and the evolution of the solar wind parameters at Earth using the ENLIL/WSA model (Odstrcil & Pizzo 2009a, 2009b).

Magnetic Flux Density Synoptic Map and Uncertainties

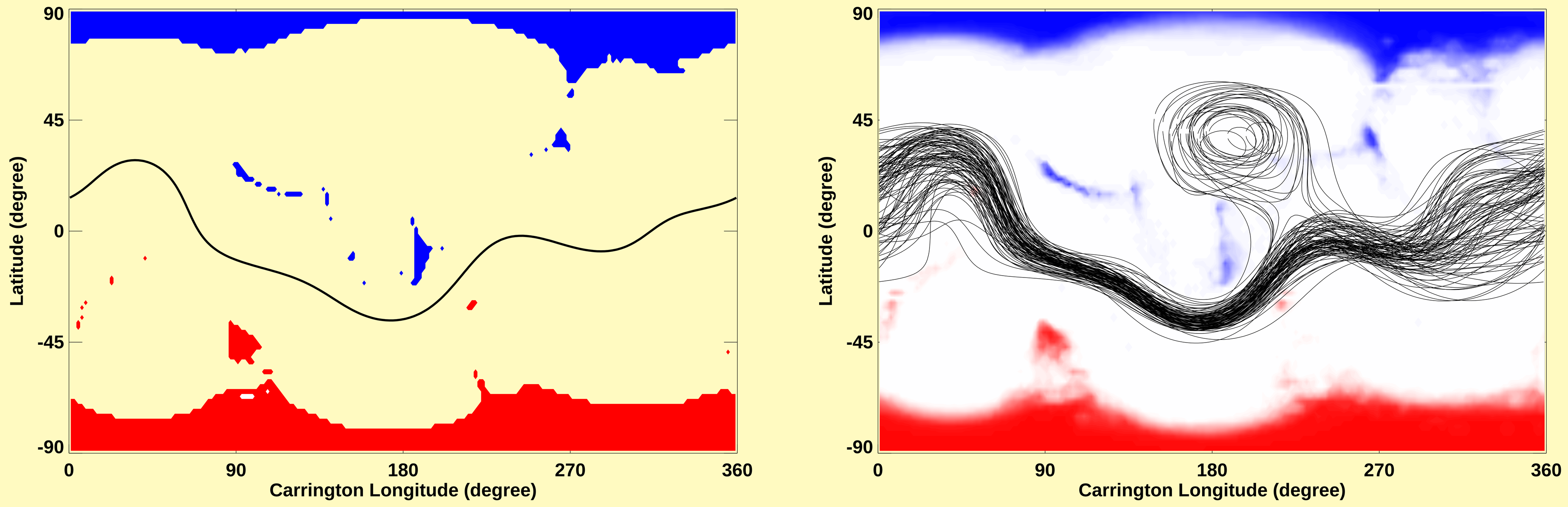


Example of a photospheric magnetic flux density synoptic chart (top) and the corresponding uncertainty map (bottom). The charts were computed using Fe I 630.15 nm SOLIS/VSM full disk longitudinal magnetic observations covering CR2104. Uncertainties are larger in areas associated with strong magnetic fields.

References

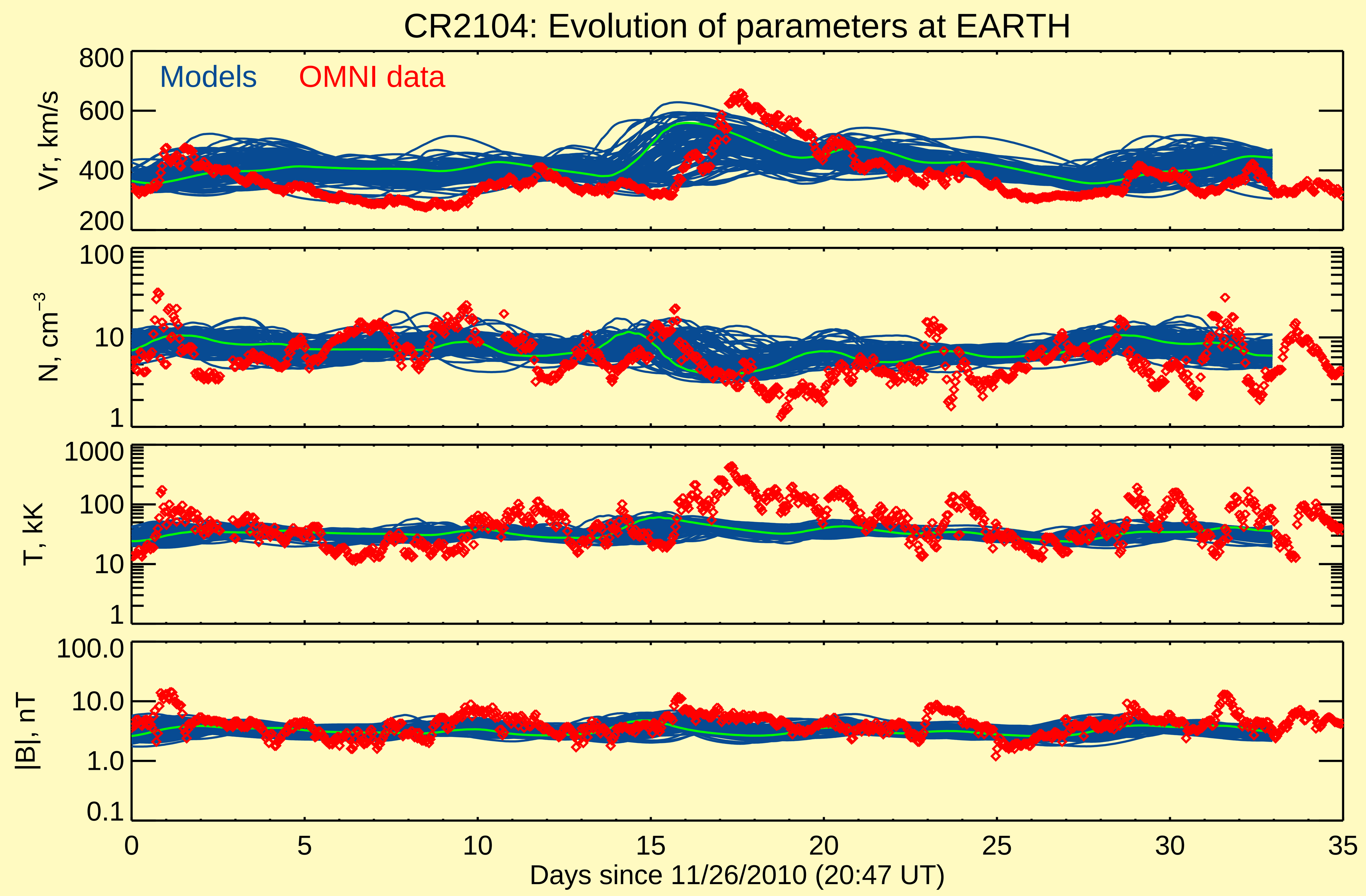
Bertello, L., Pevtsov, A.A., Petrie, G.J.D., Keys, D.: 2014, Solar Physics, 289, 2419.
Odstrcil, D., Pizzo, V.J.: 1999a, Journal of Geophysical Research, Vol. 104, Issue A1, 483.
Odstrcil, D., Pizzo, V.J.: 1999b, Journal of Geophysical Research, Vol. 104, Issue A1, 493.
Altschuler, M.D., Newkirk, G.: 1969, Solar Physics, 9, 131.

PFSS Model: Results



Left: The PFSS neutral line (thin black lines) and positive/negative open field footpoints (red/blue pixels) are shown for CR 2104. The open field footpoints correspond to coronal holes and the neutral line represents the heliospheric current sheet.
Right: The model neutral lines from the generated maps are over-plotted. Solid red/blue indicates pixels where 100% of the models have positive/negative open field, white represents footpoints where all models have closed field, and stronger/fainter coloring indicates where a larger/smaller fraction of the models have open field.
The CR2104 global coronal field is typical of coronal structure around solar minimum: the global dipole is tilted at a small angle with respect to the rotation axis so that the positive/negative coronal holes are almost entirely confined to the southern/northern hemisphere and the neutral line does not stray more than 40° from the equator. During solar minimum the large-scale structure of the corona is mostly driven by the poloidal field whereas during solar maximum the active regions play the predominant role (Bertello et al. 2014).

ENLIL/WSA Model: Results



Solid blue lines show the result produced by the ensemble of generated maps. Top to bottom: Radial velocity, proton density, temperature, and magnetic field strength. Observed values (red diamonds) are from the NASA multi-source data set website OMNI. The green solid line is the predicted value from the original magnetic flux density map assuming no uncertainties. The observed data tend to lie within the spread of the model results, reflecting both the relative simplicity of the solar wind structure during solar minimum and the contribution from including uncertainties into the model. **In conclusion, the incorporation of uncertainties in the maps that drive the models helps to reduce the discrepancy between predicted and observed values. In some cases quite significantly.**